COMPETITION AND YIELD ADVANTAGES IN MIXED INTERCROPPING OF BARLEY AND WHEAT UNDER STRESS LEVELS OF MOISTURE DEFICIT

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Mixed intercropping of barley and wheat has been reported as the practice of smallholder farmers in some dryland areas of Ethiopia. However, this cropping system has not yet received the attention of research. Therefore, this study was conducted to determine the level of competition and yield advantage in barley and wheat mixed intercropping under different stress levels of moisture deficit.

One pot and one field experiments were conducted to address these objectives. In the pot experiment, three irrigation water levels (75-80, 50-55, and 25-30% depletion of soil available water), five intercropping ratios (%) of barley to wheat in a replacement series (100/0, 75/25, 50/50, 25/75, and 0/100), and four planting densities (4, 8, 12 and 16 plants/pot) were studied in a split-split plot design and had three sets so as to harvest at tillering, heading and maturity stages. In the field, the five intercropping ratios and the four water levels supplied by sprinkler irrigation system were studied in a split-plot design. Intra- and inter-specific competition decreased with decreasing stress levels of moisture deficit; but increased with increasing planting densities in all harvesting stages in the pot experiment. However, both competition types were higher at tillering stage but progressively decreased in later harvesting stages. Intraspecific competition was more important for barley at early stages and for wheat at later stages of the growing period. Both pot and field experiments proved that barley was less competitive than wheat towards the reproductive stage. Yield advantage of mixed intercropping of barley and wheat increased with increasing stress levels of moisture deficit under study. Yield advantage and productivity tended to be dominated by the higher yielding crop species in the mixture. This result suggests mixed intercropping of barley and wheat is not a priority in areas where moisture is not limiting in amount and distribution. It is advisable to use 50%barley + 50%wheat ratio since it is difficult to predict which crop performs better than the other in such unpredictable rainfall conditions of the drylands.

***Key words**: Barley, Wheat; Mixed intercropping, Competition; Yield advantage*

Mixed intercropping is defined as growing two or more crops simultaneously with no distinct row arrangement (Andrews and Kassam, 1976). Wheat and barley mix intercropping has been practiced by smallholder farmers in some drylands of Ethiopia (Agmas *et al*, 1998;). Mixed intercropping by smallholder farmers are greater stability of yield and better yield advantage as compared to sole crops in the face of recurrent and intermittent droughts in drylands (ICRA, 1997). However, unlike cereal-legume intercropping, the scientific information available on the cereal-cereal intercropping in general and on barley and durum wheat mixed intercropping in particular is very limited. Moreover, as there are advantages in intercropping, there are also disadvantages mainly attributable to competition effect (Willey, 1979).

The specific factors that lead to better than expected yields of mixtures, and to good competitive ability of cultivars and species are difficult to predict and must be evaluated on a case-by-case basis (Juskiw *et al*, 2000). Some of the factors affecting the level of productivity and competition in intercropped mixtures are resource availability (such as water), plant density, proportion of one species to another, and the relative roles of intra- and inter-specific interactions are key factors (Roush *et al*, 1989, Sharaiha *et al*, 2004), in addition to morphological and growth behaviors of each components. Thus, time of plant emergence, root establishment, plant height, leaf area, and early growth in general are reported to play an important role in competition for resources (Cousens *et al*, 1991). Therefore, the objectives of this study were to determine the level of competition and yield advantage in barley and wheat mixed intercropping under different stress levels of moisture deficit.

MATERIAL AND METHOD

Pot experiment

The pot experiment was conducted at Jubeiha Agricultural Research Station in the campus on the University of Jordan in an open air condition in the summer 2002. The surface soil (0-30cm depth) of the research farm in the campus of the University of Jordan was used for this experiment. The texture class of the soil was clay loam with 20% sand, 44% silt and 36% clay content as determined by the hydrometer method (Ryan *et al*, 1996). Soil moisture content at field capacity and permanent wilting point on weight basis was 30% at -0.3 bar and 12.45% at -15 bar as determined by the ceramic plate apparatus (Misra and Ahmed, 1987). Each pot was filled with 7.55 kg dry soil. Pot size was 24 cm in diameter and 20 cm in depth. The design used was split-split plot in RCB of three replications. The main plot treatments were the three irrigation water levels: W_1 = 75-80%; W_2 = 50-55%; and W_3 = 25-30% depletion of soil available water. The subplot treatments were the five intercropping ratios (%) of barley to wheat: 100/0, 75/25, 50/50, 25/75 and 0/100 in a replacement series. The crop varieties used in this experiment were ***Rum*** for barley (***Hordeum vulgare***) and ***Cham$_1$*** for durum wheat **(*Triticum durum*.)** The sub-sub plot treatments were the four planting densities: 4, 8, 12 and 16 plants/pot (equivalent to 88, 177, 265 and 354 plants/m^2). There were three complete sets of the same experiment so as to have harvests at tillering (25 days after emergence), heading (45 days after emergence) and maturity stages in order to evaluate competition and yield advantage of the cropping systems at these stages.

Fertilizer at a rate of 21 kg/ha P and 64 kg/ha N was calculated for the area of each pot and applied before sowing. Sowing was done 24 hrs after watering each pot to field capacity. The sowing date was 24-27 May 2002. and harvested on August 30th. Treatment of each irrigation water level was started 5 days after emergence. When the fixed depletion level was reached for the irrigation water level, all pots were weighed in that irrigation water level and the calculated water balance for each pot was replenished back to field capacity. Salter balance with 20 kg capacity and 5 g division was used to weigh pots.

Data collection

All plant character measurements in weight were taken after oven drying in an oven at 70°C for 48hrs.

Biomass yield/plant: dry weight of above ground biomass of all plants harvested for each crop species in a pot was divided by its planting density in that pot, for each harvesting stage.

Biomass yield/pot: weight of above ground biomass of all harvested plants in a pot, for each harvesting stage.

Grain yield/pot: weight of grains harvested from a pot.

Grain yield/plant: dry weight of grains from all harvested plants per pot for each crop species was divided by planting density of each crop species in that pot.

Root weight/pot: dry weight of roots in a pot after being washed on 5 mm sieve, for each harvesting stage.

Data analyses and interpretation

The analysis of several complete replacement series experiments at a range of total densities as proposed by Jolliffe *et al* (1984) is done by using the reciprocal yield model for multiple species. Thus the competition between two species can be examined using multiple regression models of the reciprocal yield (Spitters, 1983):

$1/w_1 = b_{10} + b_{11}N_1 + b_{12}N_2$ (1) $1/w_2 = b_{20} + b_{22}N_2 + b_{21}N_1$ (2)

where w_1 and w_2 are the weights of plants of species 1 and 2; b_{10} and b_{20} are the reciprocals of weights of plants of species 1 and 2 that are free from competition; b_{11} and b_{22} are the regression coefficients for intraspecific interference; $b_{12}$and b_{21} are the regression coefficients for interspecific interference; and N_1 and N_2 are the densities of plants of species 1 and species 2, respectively.

Competitive ability in reciprocal yield model is calculated by dividing the coefficient of intraspecific competition (b_{11} or b_{22}) by the coefficient of interspecific competition (b_{12} or b_{21}). Thus, the equation to quantify the competitive ability of each species when the two crop species are in mixed culture (Spitters, 1983):

Competitive ability of species 1 (a_1) = b_{11}/b_{12}(3) Competitive ability of species 2 (a_2) = b_{22}/b_{21} (4)

To determine if the two species were competing for the same resources, the niche differentiation index (NDI) can be calculated as (Spitters, 1983):NDI = (b_{11}/b_{12}) x (b_{22}/b_{21}) (5).

NDI > 1 indicates that there is niche differentiation, the species in the mixture capture more resources and are utilizing resources better than they do as sole crops. NDI < 1 indicates some kind of inhibition caused by competition for the same resources and that the species are eliminating one another. NDI = 1 indicates that the two species are competing equally for the same resources.

The most important index of biological advantage is the relative yield total (RYT) that was used to quantify the yield advantages in a replacement series (Mead, 1986). The equation for RYT, when two species are intercropped:

$RYT = X_{mix}/X_{sole} + Y_{mix}/Y_{sole}$ (6)

where X_{mix} and Y_{mix} are yields of species X and Y in mixture, and X_{sole} and Y_{sole} are yields of species X and Y as sole crops. Values of RYT > 1 indicate that the species make different demands on resources or avoid competition in some way, while values of RYT < 1 imply mutual antagonism (Harper, 1977). RYT values of 1 indicate that the components fully share the same limiting resource, i.e. compete fully and show no resource complementarity. Statistical significance of deviations of relative yield total (RYT) from unity was determined with a one sample T-test as used by many workers like Patterson and Highsmith (1989).

Field experiment

The field experiment was sown in 7 March 2003 and harvested on June 4th at the University of Jordan Research Station in the Jordan Valley so as to use the available sprinkler irrigation facility and to minimize rainfall interference. Experimental design was split plot in four replications. The four water levels (W_1, W_2, W_3 and W_4) were main plot treatments. The sub plot treatments were the five intercropping ratios (%) of barley to wheat in a replacement series: 100/0, 75/25, 50/50, 25/75 and 0/100. The sprinkler line source was used to apply irrigation water levels. The amount of irrigation water applied for main plots was measured using catch cans, by placing one at the center of each plot selected to represent W_1, W_2, W_3, and W_4 perpendicular to the line source on both sides. Three tensiometers for each 15 and 30cm depths on W_4 (the highest irrigation water level) were installed at sowing so as to apply irrigation whenever the tensiometer readings reach 0.75-0.85 bar. One access tube to a depth of 90cm was installed for each sub plot in each irrigation water level in one replication so as to monitor soil moisture with a neutron meter (Hydroprobe, model 503 DR, Martinez, CA USA CPN corporation). The neutron meter was calibrated for the experimental site. Neutron meter readings were set in 15cm depth intervals, starting from the upper 7.5cm depth. Water content of 0-15cm depth was also determined gravimetrically at the time of neutron meter reading. Deep percolation was assumed negligible based on neutron meter readings, and runoff was none as irrigation was applied with no runoff. Therefore, change in soil moisture content was estimated based on the content at sowing and maturity. *Table 1* shows some soil physical characteristics of the experimental site. *Table 2* shows source of water and total water use of crops under each water level treatment of the crop growing period.

Data collected

At maturity, one quadrant sample with an area of 1m^2 was harvested close to the soil surface from the center of each plot for estimating competitive ability and yield advantage based on air dried above ground biomass and grain yield.

Data analyses and interpretation

Relative Crowding Coefficient (RCC), as was reviewed by Willey (1979); measures competitive ability of crop species in a mixture assuming that mixture treatments form a replacement series. The crowding coefficient product also shows which combinations do, or do not, give a yield advantage. The equation for species a in mixture with species b in a replacement series can be written:

$$RCC_{ab} = (Y_{ab} * Z_{ba})/((Y_{aa} - Y_{ab}) * Z_{ab}) \quad (7)$$

$$RCC_{ba} = (Y_{ba} * Z_{ab})/((Y_{bb} - Y_{ba}) * Z_{ba}) \quad (8)$$

where;

Y_{aa} = Sole crop yield of species a;

Y_{bb} = Sole crop yield of species b;

Y_{ab} = Mixture yield of species a (in combination with b);

Y_{ba} = Mixture yield of species b (in combination with a);

Z_{ab} = Sown proportion of species a (in mixture with b);

Z_{ba} = Sown proportion of species b (in mixture with a).

Each species has its own relative crowding coefficient (RCC). If a species has a coefficient less than, equal to, or greater than one it means it has produced less yield, the same yield, or more yield than expected, respectively. The component crop with the higher coefficient is the dominant one.

Table 1

Some soil physical characteristics of the experimental site of the field experiment at Jordan Valley in 2003

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture class	Bulk density (g/cm^3)	FC (Pv %)	PWP (Pv %)
0-15	62	18	20	Sandy loam	1.62	25.16	7.74
15-30	62	16	22	Sandy clay loam	1.65	26.12	9.31
30-45	62	18	20	Sandy loam	1.70	27.44	9.35
45-60	60	20	20	Sandy loam	1.79	27.08	9.52
60-75	60	18	22	Sandy clay loam	1.87	27.56	9.71
75-90	64	18	18	Sandy loam	1.88	27.15	8.80

FC (Pv%) = Percent field capacity in volume.
PWP (Pv%) = Percent permanent wilting point in volume.

Table 2

Source of water and total water use of crops under each water level treatment in the field experiment at Jordan Valley, 2003

Water level	Extracted from soil (mm)	Irrigated water (mm)	Rainfall (mm)	Total water use (mm)
W1	68.44	50.05	49.8	168.29
W2	67.19	89.66	49.8	206.65
W3	67.18	113.66	49.8	230.64
W4	56.09	132.17	49.8	238.06

RESULTS AND DISCUSSIONS

Pot experiment. Competition

Coefficients of intra- and inter-specific competition, relative competitive ability and niche differentiation values at different growth stages and irrigation water levels are presented in Table 3. At tillering stage, intraspecific competition was greater than interspecific competition for barley in all irrigation water levels. This means that biomass yield of barley was more affected by competition within itself than the competition with wheat. The reverse was true for wheat in all irrigation water levels at tillering stage. Again this means biomass yield of wheat was more affected by the competition with barley. The coefficients at tillering stage also indicate that increase in planting density increased intraspecific competition for barley and interspecific competition for wheat more than interspecific competition for barley and intraspecific competition for wheat.

According to harvests at heading stage of barley and at maturity stage of each crop species, intraspecific competition was greater than interspecific competition in all irrigation water levels for both of barley and wheat. This means that biomass yield of each crop species was more affected by competition within itself than with the other species. For grain yield at maturity, intraspecific competition was again greater than interspecific competition for barley and wheat in all irrigation water levels.

Both intra- and inter-specific competition decreased with the increase of irrigation water levels. The highest intraspecific competition coefficient of 0.16 for barley at tillering stage in W_1 declined to 0.025 in W_3; and the interspecific competition coefficient of 0.059 in W_1 declined to 0.004 in W_3. Intra- and inter-specific competition for biomass yield also decreased in later growth stages. More over, the highest intraspecific competition coefficient (0.150) of wheat in W_1 at tillering stage declined to 0.046 at heading and 0.037 at maturity in W_1; the highest interspecific competition coefficient (0.220) at tillering stage in W_1 declined to 0.026 at heading and 0.024 at maturity in W_1.

Relative competitive values indicated that barley was more competitive than wheat at tillering stage. For example, the relative competitive ability of barley at tillering stage in W_1 was 2.70, indicating that one barley plant was equivalent to 2.70 wheat plants; while that of wheat was 0.682, indicating that one wheat plant was equivalent to 0.68 plant of barley. However, this was reversed in periods from heading to maturity. For example, the relative competitive ability of barley biomass at maturity in W_1 was 1.242, while that of wheat was 1.588.

Severity of intra- and inter-specific competition increased with increasing planting densities in all irrigation water levels and harvesting stages. However, increasing planting densities increased intraspecific competition more than that of interspecific competition in all growth stages for barley, and in heading and maturity stages for wheat. Increasing planting densities increased interspecific competition more than that of intraspecific competition for wheat at tillering stage. Intraspecific competition increased more than interspecific competition for barley with the increase of barley ratio in all irrigation water levels, planting densities and harvesting stages. Increasing wheat ratio increased intraspecific competition more than interspecific competition for wheat in all irrigation water levels and planting densities at heading and maturity stages. But at tillering stage, increasing wheat ratio reduced interspecific competition more than it increased intraspecific competition for wheat.

Niche differentiation index was consistently more than one in all growth stages and irrigation water levels, indicating that there was yield advantage in mixed cropping, the two crop species in the mixtures captured more resources and were utilizing resources probably better than they did as sole crops.

Table 3

Coefficients of intra- and inter-specific competition, relative competitive ability and niche differentiation values under different harvesting stages and irrigation water levels in the pot experiment

Irrigation water levels	B_{bb}	B_{bw}	W_{ww}	W_{wb}	RC_b	RC_w	NDI	^{2} of $1/W_b$	R^2 of $1/W_w$
For above ground biomass yield at tillering stage									
W_1	0.160	0.059	0.150	0.220	2.700	0.682	1.841	0.913	0.976
W_2	0.061	0.032	0.067	0.090	1.930	0.751	1.449	0.939	0.967
W_3	0.025	0.004	0.022	0.049	6.388	0.446	2.849	0.859	0.919
For above ground biomass yield at heading stage									
W_1	0.0541	0.008	0.046	0.026	6.503	1.787	11.621	0.901	0.796
W_2	0.027	0.022	0.029	0.016	1.188	1.795	2.132	0.907	0.930
W_3	0.015	0.011	0.020	0.013	1.345	1.507	2.027	0.998	0.974
For above ground biomass yield at maturity stage									
W_1	0.052	0.042	0.037	0.024	1.242	1.588	1.972	0.923	0.928
W_2	0.028	0.020	0.018	0.010	1.394	1.745	2.433	0.966	0.970
W_3	0.013	0.009	0.011	0.006	1.413	1.663	2.350	0.955	0.984
For grain yield at maturity stage									
W_1	0.266	0.157	0.131	0.050	1.694	2.617	4.433	0.892	0.906
W_2	0.068	0.049	0.055	0.030	1.368	1.847	2.527	0.851	0.962
W_3	0.033	0.020	0.032	0.023	1.672	1.363	2.279	0.931	0.991

Each value was averaged over 3 replications.

Number of samples (n) = 16 (or 4 density x 4 ratio) for each stage; B_{bb} = coefficient of intraspecific competition for barley; B_{ww} = coefficient of intraspecific competition for wheat.; B_{bw} = coefficient of interspecific competition of wheat on barley; B_{wb}= coefficient of interspecific competition of barley on wheat; RC_b = relative competitive ability of barley; RC_w = relative competitive ability of wheat; NDI = niche differentiation index; R^2 of $1/W_b$ = coefficient of determination for the reciprocal yield model equation of barley; R^2 of $1/W_w$ = coefficient of determination for the reciprocal yield model equation of wheat.

Yield advantage

Effects of irrigation water levels on relative yield totals of intercropping ratios under different harvesting stages are presented in Table 4. Combination of W_1 with 50%B + 50%W mixture at tillering, and with 75%B + 25%W mixture at heading and maturity stages gave the highest relative yield totals of 1.128 (about 13% yield advantage), 1.194 (about 19% yield advantage) and 1.229 (about 23% yield advantage), respectively, for biomass yield. Averages of relative yield totals across irrigation water levels and intercropping ratios for each harvesting stage indicated that yield advantage for biomass yield increased in later growth stages, the lowest being at tillering stage. Average of relative yield totals across intercropping ratios for each irrigation water level in each harvesting stage indicated that yield advantage generally decreased with the increase of irrigation water levels. Intercropping ratio of 50%B + 50%W mixture had higher relative yield totals than other mixtures in most of the harvesting stages and irrigation water levels for biomass yield, and was the best for grain yield. For grain yield, combination of W_1 with 50%B + 50%W and 75%B + 25%W mixtures gave the highest and the second highest relative yield totals of 1.273 (about 27% yield advantage) and 1.223 (about 22% yield advantage), respectively.

Effects of planting densities on relative yield totals of intercropping ratios under different harvesting stages are presented in *Table 5*. Combination of 4 plants/pot and 50%B + 50%W mixture gave the highest relative yield totals of 1.308 (about 31% yield advantage) and 1.245 (about 25% yield advantage) at tillering and maturity stages, respectively. Combination of 8 plants/pot and 50%B + 50%W mixture gave the highest relative yield total of 1.186 (about 19% yield advantage) for biomass yield at heading stage. Averages of relative yield totals across planting densities for each harvesting stage indicates that yield advantage for biomass yield increased in later stages, the lowest being at tillering stage. Even though there are few inconsistencies across harvesting stages, the general trend indicates that lower planting densities had higher yield advantages as indicated by higher relative yield totals for biomass yield. However, for grain yield combination of 16 plants/pot with 50%B + 50%W and 75%B + 25%W gave the highest and second highest relative yield totals of 1.258 (about 26% yield advantage) and 1.237 (about 24% yield advantage), respectively. Intercropping of 50% B + 50% W mixture in different planting densities and harvesting stages had higher relative yield totals than other mixtures in most of the observations.

Table 4

Effect of irrigation water levels on relative yield totals of intercropping ratios under different harvesting stages in the pot experiment

	75%B + 25%W	50%B + 50%W	25%B + 75%W	Average
Relative yield totals for biomass yield at tillering stage				
W_1	1.07	1.13*	1.07	1.09
W_2	1.01	1.07	1.01	1.03
W_3	1.01	1.00	1.03	1.01
Average	1.03	1.07	1.04	**1.05**
Relative yield totals for biomass yield at heading stage				
W_1	1.19**	1.16*	1.11*	1.16
W_2	1.05	1.08	1.05	1.06
W_3	1.12*	1.15*	1.10*	1.12
Average	1.12	1.13	1.09	**1.11**
Relative yield totals for biomass yield at maturity stage				
W_1	1.23**	1.10*	1.04	1.12
W_2	1.13*	1.19**	1.22**	1.18
W_3	1.13*	1.17*	1.14*	1.15
Average	1.17	1.16	1.13	**1.15**
Relative yield totals of grain yield at maturity stage				
W_1	1.22**	1.27**	1.03	1.18
W_2	1.18**	1.14*	1.09*	1.14
W_3	1.09*	1.10*	1.09*	1.09
Average	1.17	1.17	1.07	

Each value was averaged over 4 planting densities for each replication; Number of samples for T-test = 3 replications; *, ** = significant at 5% and 1%, respectively, at one sample T-test against the test value of 1.

Table 5

Effect of planting densities on relative yield totals of intercropping ratios under different harvesting stages in the pot experiment

	75%B + 25%W	50%B + 50%W	25%B + 75%W	Average
RYT for biomass yield at tillering stage				
4 plants/pot	1.00	1.31**	1.01	1.11
8 plants/pot	1.00	1.04	1.01	1.02
12 plants/pot	1.02	1.05	1.07	1.05
16 plants/pot	1.02	1.04	1.05	1.04
Average	1.01	1.11	1.03	**1.051**
RYT for biomass yield at heading stage				
4 plants/pot	1.12*	1.12*	1.06	1.10
8 plants/pot	1.16*	1.19**	1.15*	1.16
12 plants/pot	1.09*	1.12*	1.08	1.10
16 plants/pot	1.10*	1.10*	1.07	1.09
Average	1.12	1.13	1.09	**1.11**
RYT for biomass yield at maturity stage				
4 plants/pot	1.15*	1.25**	1.23**	1.21
8 plants/pot	1.11*	1.14*	1.09*	1.17
12 plants/pot	1.18**	1.10*	1.10*	1.13
16 plants/pot	1.21**	1.13*	1.11*	1.15
Average	1.17	1.16	1.13	**1.15**
RYT for grain yield at maturity stage				
4 plants/pot	1.15*	1.18*	1.08	1.14
8 plants/pot	1.15*	1.14*	1.03	1.11
12 plants/pot	1.12*	1.11*	1.06	1.10
16 plants/pot	1.24**	1.26**	1.12*	1.21
Average	1.17	1.17	1.07	

Each value was averaged over 3 irrigation water levels for each replication. Number of samples for T-test = 3 replications; *, ** = significant at 5% and 1%, respectively, at one sample T-test against the test value of 1.

Field experiment. Competition

Relative yield (RY) and relative crowding coefficient (RCC) values for grain and biomass yield of barley and wheat in the mixture are presented in Table 6. For grain yield, most RCC values for barley are less than those of wheat, indicating that barley was dominated by wheat in almost all irrigation water levels. Just the opposite was true for biomass yield. Even though one species dominated the other, relative crowding coefficient values greater than one for each species indicate that there was yield advantage. This was also confirmed by the relative yields greater than the expected yield for each ratio of each mixture combination in different water levels. In cases where the relative crowding coefficient of the component crop was less than one, the relative yield of that component crop was also less than the expected relative yield at that specific ratio.

The relative yield total values (*Table 7*) for biomass yield in W_2, W_3, and W_4, as well as in mixtures of 50%barley + 50%wheat and 25%barley + 75%wheat are not significantly different from unity in a one sample T-test. This indicates that the two crop species were competing for the same resource at the vegetative stage.

Table 6

Relative yield (RY) and relative crowding coefficient values of barley (B) and wheat (W) in the field experiment at Jordan Valley, 2003

Treatment	Values for grain yield				Values for biomass yield			
	RY		RCC		RY		RCC	
	B	W	B	W	B	W	B	W
W_1R_1	0.87	0.62	2.16	4.90	0.96	0.33	8.17	1.48
W_1R_2	0.52	0.73	1.06	2.68	0.75	0.49	3.06	0.95
W_1R_3	0.35	0.99	1.62	25.58	0.40	0.76	2.02	1.03
W_2R_1	0.97	0.44	12.21	2.38	0.87	0.24	2.20	0.97
W_2R_2	0.75	0.52	3.04	1.10	0.61	0.49	1.58	0.97
W_2R_3	0.37	0.89	1.76	2.70	0.35	0.68	1.60	0.72
W_3R_1	0.80	0.29	1.36	1.25	0.80	0.26	1.34	1.08
W_3R_2	0.53	0.62	1.15	1.62	0.63	0.44	1.72	0.78
W_3R_3	0.33	0.95	1.48	6.22	0.37	0.73	1.76	0.91
W_4R_1	0.67	0.40	0.67	2.00	0.79	0.28	1.24	1.18
W_4R_2	0.55	0.66	1.21	1.93	0.59	0.46	1.46	0.85
W_4R_3	0.29	0.94	1.22	5.13	0.37	0.71	1.73	0.81

Each value is average of 4 replications.
R_1 = 75/25; R_2 = 50/50; and R_3 = 25/75 barley to wheat ratio (%).

Yield advantage

Yield advantage of mixed cropping of barley and wheat increased with the decrease of Water levels (*Table 7*). The highest significant grain and biomass yield advantages of 1.49 (or RYT = 1.49) and 1.29 (or RYT = 1.29) were in 75% barley + 25% wheat mixture, respectively, in W_1. In other words, 75% barley + 25% wheat mixture gave 49% grain yield, and 29% biomass yield increase over growing the two species separately as a sole crop in W_1. The lowest yield advantage both in grain and biomass yield that was not significantly different from unity in 75%barley + 25%wheat was 1.07 (or RYT = 1.07) in W_4.

Competition and yield advantage

Pot experiment

Relative yield advantage was the lowest at tillering stage (*Tables 4 and 5*). This could be attributed to the relatively high intra- and inter-specific competitions observed at this stage (*Table 3*). Since intraspecific competition was higher than interspecific competition in barley, biomass per plant of barley decreased with increasing barley ratio in the cropping system. Interspecific competition was higher than intraspecific competition in wheat and hence biomass per plant of wheat increased with increasing wheat ratio in the cropping system (*Table 3*).

Table 7
Relative yield totals of intercropping ratios under different water levels in the field experiment

Water levels	Barley to wheat ratio (%)			Average
	75/25	50/50	25/75	
	RYT for grain yield			
W_1	1.49**	1.25**	1.34**	1.36
W_2	1.41**	1.27**	1.26**	1.31
W_3	1.09	1.15*	1.28**	1.17
W_4	1.07	1.21*	1.23*	1.17
Average	1.27	1.22	1.28	
	RYT for biomass yield			
W_1	1.29**	1.24*	1.16*	1.23
W_2	1.11	1.10	1.03	1.08
W_3	1.06	1.07	1.10	1.08
W_4	1.07	1.05	1.08	1.07
Average	1.13	1.12	1.09	

Number of samples for T-test = 4 replications; *, ** = significant at 5% and 1%, respectively, at one sample T-test against the test value of 1.

This means that barley gained in the mixture but was not enough to compensate the loss from wheat due to high interspecific competition in the mixture. Therefore, biomass yield in mixtures was not high enough to give high relative yield advantage. On the other hand, W_1 with high level of intraspecific competition gave high relative yield advantage (*Table 4*), which was also confirmed in the field experiment. This could be explained by the relatively high yield depression (be it grain or biomass) of sole crops as the result of high intraspecific competition in W_1 than in W_2 and W_3. For example, sole wheat gave about 97% and 114% biomass yield of 75%B + 25%W mixture at maturity stage in W_1 and W_2, respectively. Sole barley gave 84% and 92% biomass yield of 75%B + 25%W mixture at heading stage in W_1 and W_2, respectively. Lower planting densities at early stages and higher planting densities at later stages had higher relative yield advantage (*Table 5*). This could go in line with the decrease of intra- and inter-specific competition in later growth stages. As barley matured earlier than wheat, there could be more space to decrease interspecific competition in mixtures; thereby resulting in higher relative yield advantage in higher plant densities. For similar reasons, yield advantages in 50%B + 50%W, and 75%B + 25%W mixtures were higher at heading and maturity stages. Especially 50%B + 50%W mixture had the highest grain yield advantage.

Field experiment

Barley was consistently proved to be highly competent in early growth stages in the pot experiment. Again its dominance in biomass yield, as indicated by the higher RCC values of barley than those of wheat in biomass yield in *Table 6*, in this field experiment also shows that barley was more competitive than wheat at vegetative stages of growth. This was because barley grew faster than wheat at early stages in biomass and root weight, leaf area and plant height (data not shown) as it was observed in the pot experiment. Wheat usually dominated in the reproductive stages of this field experiment as indicated by its higher RCC values than those of barley for grain yield in *Table 6*. This result also confirms the trend observed in the pot experiment. In later growth stages the growth of wheat usually increased faster than that of barley. Moreover, more space could be left for wheat as barley approached maturity in later growth stages. All these together could make wheat dominant in the reproductive stage.

Yield advantage of mixed intercropping cropping of barley and wheat significantly increased with the decrease of irrigation water levels (*Table 7*). This was also the case in the pot experiment in which the highest yield advantage was in W_1. The contributing factor was the highest intraspecific competition which depressed yield of sole crops in W_1 as was revealed in the pot experiment. But in mixtures there was some complementarity in time with regard to demand on resources as growth rate was different for barley and wheat. Therefore, at early stage barley and at later stage wheat would get relief of high intraspecific competition when they were in mixtures than in sole crops. This trend was confirmed by the results of the pot experiment that quantified intra- and interspecific competition of barley and wheat at different growth stages. Because of such complementarity, mixed cropping of 75%barley + 25%wheat in this field experiment gave the highest yield advantage for grain and biomass yields in W_1. The second bests were 25%barley + 75%wheat mixture for grain yield and 50%barley + 50%wheat mixture for biomass yield in W_1. Especially for grain yield, wheat relative yields were by far higher than those of barley when compared to the expected. This indicates that intraspecific competition was higher in sole wheat than in sole barley in reproductive stage.

Thus, sole wheat was the lowest yielding. Even though 50%barley + 50%wheat mixture was lower than 25%barley + 75%wheat mixture in yield advantage, grain yield (526 kg/ha) of 50%barley + 50%wheat mixture was by far higher than that of 25%barley + 75%wheat mixture giving 389 kg/ha. This clearly shows that not only yield advantages but also productivity and others farmers' objectives such as stability must be considered in selecting intercropping ratio combinations for recommendation.

CONCLUSIONS

Intra- and inter-specific competition decreased with decreasing stress levels of moisture deficit; but increased with increasing planting densities in all harvesting stages in the pot experiment. However, both competition types were higher at tillering stage but progressively decreased in later harvesting stages. Intraspecific competition was more important for barley at early stages and for wheat at later stages of the growing period. Both pot and field experiments proved that barley was less competitive than wheat towards the reproductive stage.Yield advantage of mixed intercropping of barley and wheat increased with increasing stress levels of moisture deficit under study. This result suggests mixed intercropping of barley and wheat is not a priority in areas where moisture is not limiting in amount and distribution. As yield advantage and productivity tended of the intercrops tended to be dominated by the higher yielding crop component, it is advisable to use 50% barley + 50% wheat ratio since it is difficult to predict which performs better than the other in such unpredictable rainfall conditions of the drylands.

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